

Elliptical galaxy nuclei activity powered by infalling globular clusters

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Abstract. Globular cluster systems evolve, in galaxies, due to internal and external dynamics and tidal phenomena. One of the causes of evolution, dynamical friction, is responsible for the orbital decay of massive clusters into the innermost galactic regions. It is found that these clusters are effective source of matter to feed a central galactic black hole such to make it grow and shine as an AGN.

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1. Globular cluster systems in galaxies

Thanks to the high resolution of HST, as well of the power of large ground based telescopes, good data are available about the characteristics of globular clusters (GCs) in galaxies (see, e.g., Forbes et al. 1996; Elson et al 1998; Grillmair et al. 1999).

One general conclusion is that the Globular Cluster Systems (GCSs) are, usually, less centrally concentrated than the underlying star distribution (Lauer & Kormendy 1986, Harris 1986, Harris et al. 1991, Capuzzo-Dolcetta & Vignola 1997, Capuzzo-Dolcetta & Tesseri 1999, Capuzzo-Dolcetta & Donnarumma 2001). The simplest explanation is that globular clusters and halo-bulge stars, being coeval, formed with the same radial distribution in the galaxy and the present different distribution has been reached by the following evolution of the GC component. This evolution is caused by the various mechanisms acting on GCs as galaxy satellites (mainly dynamical friction and tidal interaction with the overall halo-bulge-disk stellar and gaseous component). Many authors have studied the problem of evaluating the role of these evolutionary phenomena by different points of view (Fall & Rees 1977; Capuzzo-Dolcetta & Tesseri, 1997, 1999; Gnedin & Ostriker 1997; Murali & Weinberg 1997a, 1997b; Baumgardt 1998; Vesperini 2001). In particular, Pesce, Capuzzo-Dolcetta & Vietri (1992) have shown how the role of dynamical friction is of enormous importance in the evolution of GCs in triaxial galaxies. Capuzzo-Dolcetta (1993) developed a model to study the evolution of GCSs subjected to both dynamical friction and tidal interaction with a massive galactic nucleus and found that sufficiently massive GCs in a triaxial galaxy, self-consistently modeled in the way described by Schwarzschild (1979) and Merritt (1980) lose



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enough orbital energy (E) and angular momentum (L) to be confined in a short time in the innermost region of the galaxy. These clusters form a sort of ‘supercluster’ which is a large mass *reservoir* for a compact object (a primordial black hole?) sitting there. Whenever the mass density of the supercluster rises over a certain threshold, the matter accretion onto the black hole (b.h.) may be the cause of its growing up to super-massive black hole size and of its activity as an AGN. Of course, when the mass of the b.h. gets sufficiently large it starts to shatter not only the looser, usually lighter, GCs but also the few remaining infalling massive clusters, so to halt the b.h. mass growth to an almost steady value. This means that the mechanism of b.h. mass growth is a *self-regulating*. These general results have been discussed in various papers (see for instance Capuzzo-Dolcetta & Miocchi 1998, Capuzzo-Dolcetta 2002) starting from Capuzzo-Dolcetta (1993). :

Consequently, it appears clearly defined this *scenario* for the evolution of the GCS in a triaxial galaxy:

- (i) massive GCs on *box* orbits (in triaxial galaxies) or, equivalently, on low L orbits in axisymmetric galaxies lose their orbital energy rather quickly;
- (ii) after ~ 500 Myr many GCs are limited to move in the inner galactic region where they can merge and form a *supercluster*;
- (iii) stars of the supercluster buzz around the nucleus where they may be captured by a b.h. seed there;
- (iv) consequently, energy is extracted from the gravitational field: part of it goes into e.m. radiation inducing an AGN activity while part increases the b.h. mass.

2. Black hole growth and nuclear activity

Consider three well studied galaxies having a firm evidence of presence of a nuclear b.h.: our Milky Way, M 31 and the giant elliptical M 87 in Virgo. The modern estimates of the central black hole masses available in the literature are, respectively, $2.6 \times 10^6 M_\odot$, $6.2 \times 10^7 M_\odot$ and $3.6 \times 10^9 M_\odot$. In the frame of the presence of a dense stellar system around the black hole, the simple process of spherical accretion of stars buzzing there around determines a threshold of mass density (ρ_c) of the nuclear cluster to allow an emission as an AGN, once that the minimum mass accretion rate of $1 M_\odot \text{ yr}^{-1}$ to sustain an AGN activity is assumed.

The expression of the spherical mass accretion rate is (Capuzzo-Dolcetta 2002):

$$\dot{m}(M_{\odot}yr^{-1}) = 8.2 \times 10^{-16} m_{bh}^{4/3} m_*^{-1/3} \rho_* R_* < v_* >^{-1}, \quad r_d = r_t,$$

or

$$\dot{m}(M_{\odot}yr^{-1}) = 2.8 \times 10^{-21} m_{bh}^2 \rho_* < v_* >^{-1}, \quad r_d = r_S,$$

where: the index $*$ refers to values of the supecluster stars; r_t and r_S are the ‘tidal’ and ‘Schwarzschild’s’ radius, respectively; $r_d = \max\{r_t, r_S\}$ is the ‘destruction radius’; the quantities m_* , m_{bh} , and R_* are in solar units, ρ_* in $M_{\odot} \text{ pc}^{-3}$; and $< v_* >$ (the internal stellar mean velocity) in km s^{-1} . Assuming $< v_* > = 10 \text{ km s}^{-1}$ for we get $\rho_c = 3.4 \times 10^7 M_{\odot} \text{ pc}^{-3}$ for the MW, $\rho_c = 5 \times 10^5 M_{\odot} \text{ pc}^{-3}$ for M 31 and $\rho_c = 300 M_{\odot}$ for M 87. The value of ρ_c for M87 is clearly a normal-low value for the central density of galactic GCs, while the ρ_c of M 31, even if large, is compatible with the estimated central values of some non core-collapsed GCs (see the Harris web Catalog of parameters for Milky Way globular clusters, feb. 2003, <http://physun.physics.mcmaster.ca/harris/mwgc.dat>). The value of ρ_c of the MW is high if compared with typical, non-collapsing globular clusters but totally compatible with the merging scenario previously sketched. Actually, a density of $3.4 \times 10^7 M_{\odot} \text{ pc}^{-3}$ may be reached by a pure (linear) merging of abput one hundred GCs typical in their mass and linear sizes (total mass of few $10^5 M_{\odot}$ and half mass radius of a couple of pc).

Given this plausibility of the accretion-emission mechanism, we report here of some results that will be presented in a more detailed way in a forthcoming paper. To employ the model of evolution of a GCS developed by Capuzzo-Dolcetta (2001, 2004), we refer to the triaxial galactic model developed by Schwarzschild (1979) and Merritt (1980). The system is composed by $N_0 = 1000$ single mass ($M_0 = 2 \times 10^6 M_{\odot}$) GCs whose orbital velocity dispersion (σ) defines a ‘normal’ system, as that whose $\sigma = 330 \text{ km s}^{-1}$ is equal to the average σ of stars generating the galactic potential, while the choice of $\sigma = 165 \text{ km s}^{-1}$ corresponds to a dynamically ‘cold’ system and $\sigma = 660 \text{ km s}^{-1}$ to a ‘hot’ system. Two different initial masses for the nuclear galactic b.h. are considered: $M_{n0} = 3 M_{\odot}$ and $M_{n0} = 10^6 M_{\odot}$.

Fig. 1 shows the time behaviour of the nucleus luminosity and mass (L_n and M_n), as well as of the super-cluster stellar density by mass (ρ_*). The density grows rapidly up to a plateau at $\rho_* \sim 4.3 \times 10^7 M_{\odot} \text{ pc}^{-3}$ in the case of the colder GCS; in the other two cases studied, ρ_* shows a similar (later) quick growth up to a maximum ($\sim 2 \times 10^7 M_{\odot} \text{ pc}^{-3}$ and $\sim 1.2 \times 10^7 M_{\odot} \text{ pc}^{-3}$ for $\sigma = 330 \text{ km s}^{-1}$ and $\sigma = 660 \text{ km s}^{-1}$, respectively) followed by a slower increase regime whose slope is greater for greater σ ’s. These behaviours of ρ_* have a correspondence in the

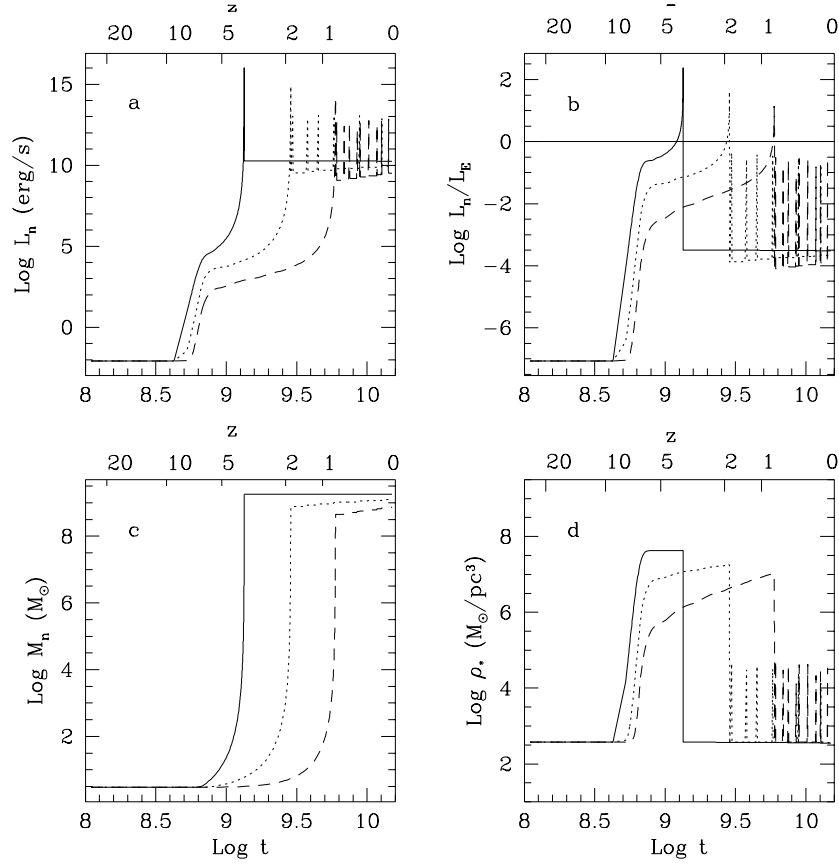


Figure 1. This figure refers to the model with $M_{n0} = 3 M_{\odot}$. Panel a: time evolution of the galactic nuclear luminosity induced by GC mass accretion; solid line refers to the *cold* GCS; dotted to the *normal* GCS; dashed to the *hot* GCS (time is in yr in Log scale; the upper abscissa is the corresponding red-shift in the Einstein-De Sitter model). Panel b: nuclear luminosity in units of Eddington's luminosity. Panel c: time evolution of the galactic nuclear (black hole) mass. Panel d: time evolution of the supercluster star mass density.

time behaviour of L_n (Fig. 1 a,b) that shows a fast growth followed by a more gentle rise up to a short-duration super-Eddington peak followed by a sudden fall to a level determined by the accretion of the black hole by stars of the bulge. The interval of redshift of the luminosity peak is $0.75 \leq z_{peak} \leq 3.7$, in the assumption of an Einstein-de Sitter universe. Notice (Fig. 1 c) that in the interval of time from 1.3 Gyr (*cold* GCS) to 6 Gyr (*hot* GCS) the black hole mass grows from the stellar size up to the values of very massive black holes: $1.8 \times 10^9 M_{\odot}$, $7.5 \times 10^8 M_{\odot}$

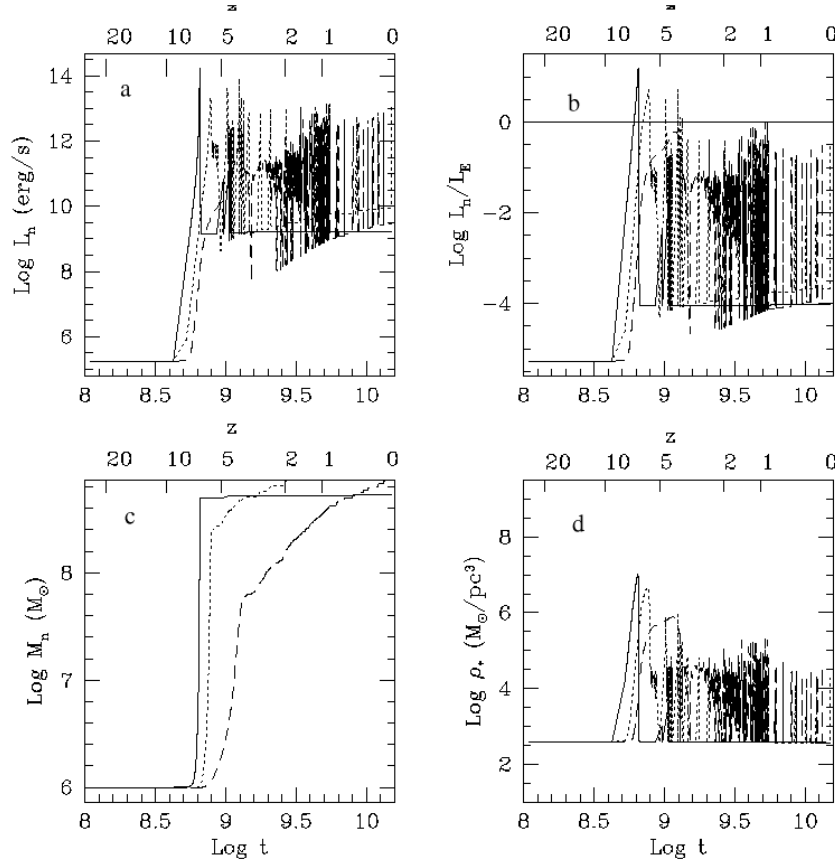


Figure 2. As in Fig. 1, for the model with $M_{n0} = 10^6 M_{\odot}$.

and $7.4 \times 10^8 M_{\odot}$, in the three cases studied (cold, normal, hot). Note that a factor 4 in σ corresponds to just a factor 2 in the final M_n . Fig. 2 refers to the results of the model with $10^6 M_{\odot}$ as initial value of the central black hole mass. As expected, the AGN activity is shifted backward in time ($6.6 \times 10^8 \text{ yr} \leq t_{peak} \leq 1.3 \text{ Gyr}$, corresponding to $7.6 \leq z_{peak} \leq 3.5$). The maximum luminosity reached by the AGN is lower than in the case of a b.h. seed of stellar origin; this because the massive b.h. is able to swallow stars of the forming supercluster before it has grown up to very large densities. Actually, as seen in Fig. 2 d, the ρ_* profile does not show the regular two-slope behaviour of the case of an initial small black hole. In the case of $M_{n0} = 10^6 M_{\odot}$, the time evolution of the nucleus mass is such that the colder GCS induces, as usual, the fastest growth while the value of the black hole mass reached at the, almost, steady state is smaller than in the case of

greater average orbital energy of GCs (see Fig. 2 c). The explanation for this is that in the case of the cold GCS the rapid fall of GCs in the central region causes the subsequent quick growth of both M_n and L_n : M_n reaches rapidly a value large enough to shatter tidally the incoming, lighter GCs. This means that there is no more way to accrete furtherly the b.h. after the fast consumption of the residual supercluster. In this case, the galaxy is spoiled of all its GCs in a time much shorter than the Hubble time. Among the cases studied here, only the cold and normal GCSs in the case of $M_{n0} = 10^6 M_\odot$ suffer of the nucleus tidal erosion, able to destroy 74% and 3% of the initial population, respectively. An interesting result is that the values of the steady (final) black hole mass are quite similar in the various cases studied here: the range of values of the present day central black hole is $0.7 \div 2 \times 10^9 M_\odot$.

3. Conclusions

The difference observed among the radial distributions of the family of globular clusters and bulge-halo stars in galaxies can be explained in terms of evolution of the globular cluster system. The evolution of massive clusters is dominated by dynamical friction, whose effect is enhanced in triaxial galaxies, while tidal effects are relevant just when a very massive nucleus is initially present or evolutively accreted. The dynamical friction braking is able to carry a huge amount of mass in the inner galactic regions in less than 1 Gyr: this provides mass and gravitational energy to a central black hole to grow to and radiate as AGN.

Of course, all these results should be confirmed by direct simulations of globular cluster merging in the inner galactic regions (work started by Capuzzo-Dolcetta & collaborators via direct N-body simulations and presently under way) as well as by a larger set of self-consistent triaxial galactic models, without (Capuzzo-Dolcetta & Vicari 2004) and with a density cusp (Capuzzo-Dolcetta, Merritt & Vicari 2004). The preliminary results seem to confirm the general validity of the results presented here.

References

- Baumgardt, H. The initial distribution and evolution of globular cluster systems *A&A*, 330:480-491,1998
- Capuzzo-Dolcetta, R. The Evolution of the Globular Cluster System in a Triaxial Galaxy: Can a Galactic Nucleus Form by Globular Cluster Capture? *ApJ*, 415:616-630, 1993

- Capuzzo-Dolcetta, R. Galactic Nuclear Activity Induced By Globular Cluster Merging In E. K. Grebel and W. Brandner , editors, *Proceedings of the International Congress, Modes of Star Formation and the Origin of Field Populations*, ASP Conference Proceedings, Vol. 285:389, 2002
- Capuzzo-Dolcetta, R. Galactic Nuclei Activity Powered by Globular Cluster Mass Accretion in preparation, 2004
- Capuzzo-Dolcetta, R., Donnarumma, I. Evolution of globular cluster systems in three galaxies of the Fornax cluster *MNRAS*, 328:645-652,2001
- Capuzzo-Dolcetta, R., Merritt, D. and Vicari, A. Globular cluster system evolution in cuspy elliptical galaxies in preparation, 2004
- Capuzzo-Dolcetta, R. and Miocchi, P. Galactic nuclei activity sustained by globular cluster mass accretion *P&SS*, 46 (11-12):1519-1581, 1998
- Capuzzo-Dolcetta, R., Tesseri, A. Evolution of the globular cluster system of a triaxial galaxy *MNRAS*, 292:808,1997
- Capuzzo-Dolcetta, R., Tesseri, A. Globular cluster system erosion and nucleus formation in elliptical galaxies *MNRAS*, 308:961-968, 1999
- Capuzzo-Dolcetta, R. and Vicari, A. Dynamical friction on Globular Clusters in core-triaxial galaxies: is it a cause of massive black hole accretion ? submitted to *MNRAS*, 2004
- Capuzzo-Dolcetta, R., Vignola, L. Have many globulars disappeared to the galactic centres? The case of the Galaxy, M 31 and M 87 *A&A*, 327:130-136,1997
- Elson, R. A. W., Grillmair, C. J., Forbes, D. A., Rabban, M., Williger, G. M. and Brodie, J. P. HST imaging of the globular clusters in the Fornax cluster - NGC 1379 *MNRAS*, 295:240-250,1998
- Fall, S. M., Rees, M. J. Survival and disruption of galactic substructures *MNRAS*, 181:37P-42P, 1977
- Forbes, D. A., Franx, M., Illingworth, G. D. and Carollo, C. M. Ellipticals with Kinematically Distinct Cores: WFPC2 Imaging of Globular Clusters *ApJ*, 467:126-144, 1996
- Gnedin, O. Y., Ostriker, J. P. Destruction of the Galactic Globular Cluster System *ApJ*, 474:223-255,1997
- Grillmair, C. J., Forbes, D. A., Brodie, J. P., Elson, R. A. W. Hubble Space Telescope Imaging of the Globular Clusters in the Fornax Cluster: Color and Luminosity Distributions *AJ*, 117:167-180,1999
- Harris, W. E. Globular clusters in galaxies beyond the local group. V - The giant ellipticals reconsidered *AJ*, 91:822-841,1986
- Harris, W. E., Allwright, J. W. B., Pritchett, C. J., van den Bergh, S. The luminosity distribution of globular clusters in three giant Virgo ellipticals *ApJS*, 76: 115-151, 1991
- Lauer, T. R., Kormendy, J. The core of the M87 globular cluster system *ApJL*, 303:L1-L4,1986
- Merritt, D. A numerical model for a triaxial stellar system in dynamical equilibrium. II - Some dynamical features of the model *ApJS*, 43:435-455, 1980
- Murali, C. and Weinberg, M. D. The effect of the Galactic spheroid on globular cluster evolution *MNRAS*, 288:749-766, 1997a
- Murali, C. and Weinberg, M. D. Evolution of the Galactic globular cluster system *MNRAS*, 291:717-731, 1997b
- Pesce, E., Capuzzo-Dolcetta, R. and Vietri, M. Dynamical friction in a non-rotating triaxial galaxy - The effect on box orbits. *MNRAS*, 254:466-476, 1992
- Schwarzschild, M. A numerical model for a triaxial stellar system in dynamical equilibrium *ApJ*, 232:236-247, 1979

Vesperini, E. Evolution of globular cluster systems in elliptical galaxies - II. Power-law initial mass function *MNRAS*, 322 (2):247-256, 2001